The GaAs IC business never so healthy!

Alan Mills

The GaAs IC Symposium is usually a forum for the best papers from around the World in GHz microelectronics, and GaAs IC-21, held in Monterey, CA, USA (17-20 October 1999), was no exception. State-of-the-art reports were presented covering the main technology groups – wireless and broadband, very high speed digital communications, very efficient linear power amplifiers, interface electronics and signal processing, mm wave defence and commercial systems – with many of these reporting higher operating frequencies. Healthy growth rates were again being forecast – mostly fuelled by the demand from high-speed terrestrial and satellite communications systems and from cellular telephone market growth.

During the past few years, the rapid growth of gallium arsenide IC demand was driven by the rapid increase in mobile phone usage. Today however, the growth of GaAs device markets is also being extended by a demand from other rapidly growing markets most of which use multi-gigabit data stream applications. Examples of these are auto radar, terrestrial and satellite telecommunications technology, wireless data, leading edge fibre optic systems, automatic test systems and wireless telephony. The estimated relative growth rates for these product groups are shown in Figure 1. Most of this new growth is a direct consequence of the ever-increasing need for more bandwidth, motivated by the technical demands of the digitized multimedia. For example, the frequency requirements are 1.5 megabits per second (Mbps) for compressed MPEG2 format real time video, and 8 Mbps for DVD. Therefore carrier frequencies need to be orders of magnitude higher to be able to carry the increased volume of traffic, wired or wireless, and most fall within the application range of GaAs ICs.

Market demand

Indeed, the consensus is that the GaAs Revolution may only just have started. The data projections in Figure 2 cover three key demand markets: wireline data, wireline voice and wireless applications. Notably, wireline data demand will exceed the rapidly growing voice and wireless communications demand in the next few years, with most of the high frequency device-requirements for these technologies being met by GaAs materials.

A comparison of frequency performance versus breakdown voltage for the main competing material groups is given in Figure 3 and it shows good support for GaAs ICs in the demand frequency range. Although the data in Figures 2 and 3 portend an excellent outlook for GaAs-based devices, there are technical hurdles still to overcome before total success can be achieved, plus the fact that there is stiff competition from the SiGe and InP materials systems lurking in the wings at the opposite ends of the frequency spectrum of interest.

Existing GaAs IC sales represent a multi-billion-dollar market, with an estimated US$2 billion value in 1999. It is forecast by Strategies Unlimited (Mountain View, CA, USA) to grow to $4 billion in 2003 and the growth rate trends for the same period were given in Figure 1. From this data it can be seen that the highest growth rates are forecast for the automotive and satellite market segments, but mobile telephones are expected to be the largest

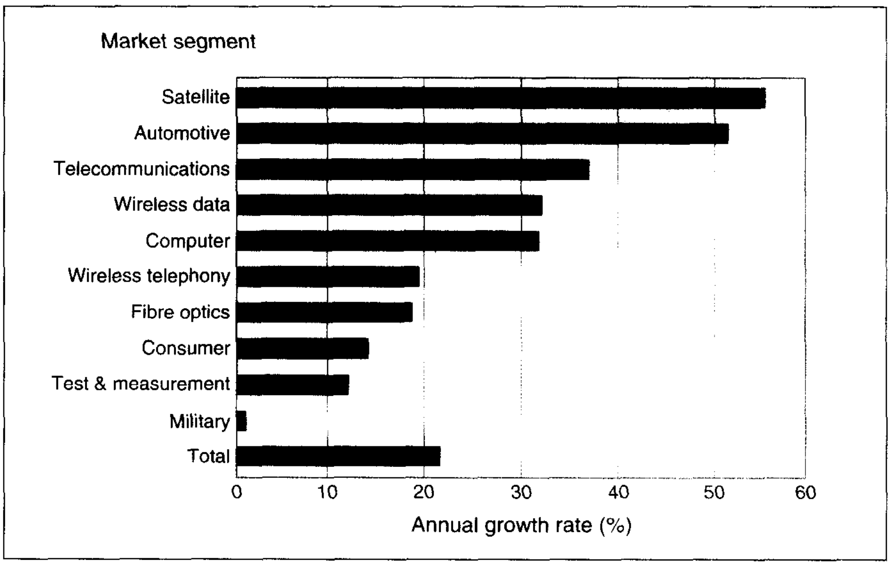

Figure 1. Growth rate trends for GaAs IC markets 1999-2003 (source: Strategies Unlimited).

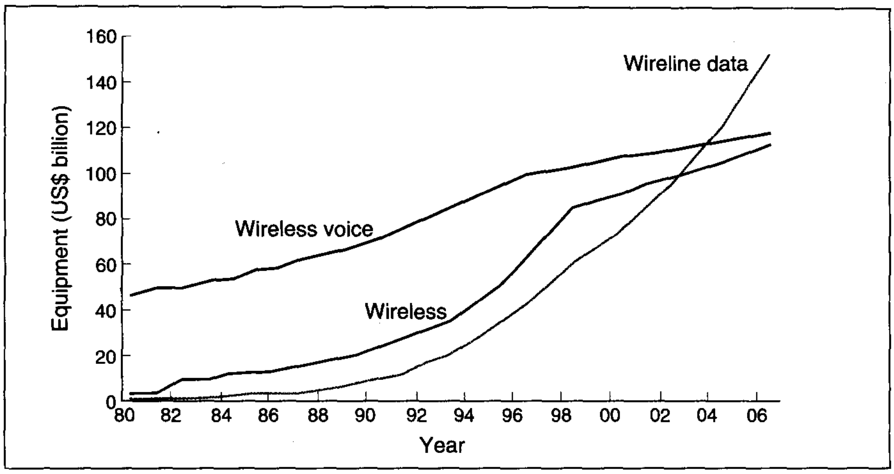

Figure 2. The evolution of communication methods (courtesy of Motorola).

single application for GaAs based ICs during the next five years. Figure 4 shows that the projected size of this market segment will increase from 221 million units in 1999 to 505 million in 2003. Respectively, these unit values are expected to contribute $1.1 and $2.2 billion in annual GaAs IC chip sales.

Thus the whole market continues to look strong in spite of active and well-publicized competition from Si and SiGe ICs such that recent growth values for GaAs IC segments have been running in the 12 to 15% per quarter range. The 1999 addition of 6" wafer capacity by several companies will allow higher production volumes and lower prices, further increasing the competitive ability for most GaAs ICs in their respective markets.The growth rates and market potential for GaAs ICs continue to be one of the hottest topics in the III-V industry.

Automatic testing

An interesting example of a lower volume niche market, but high technology GaAs IC growth market, is the Automatic Test Equipment (ATE) segment, which is typically in need of the most advanced circuitry to test the latest silicon chips operating at ever higher frequencies. Therefore, ATE manufacturers must use high-speed GaAs ICs for the most demanding performance of their systems. Most of the ICs to be tested are large chips and there is an obvious need to keep device-testing costs at reasonable levels. Thus, only about one minute is used (or allowed) to test a Pentium microprocessor chip. For microprocessor and memory chip test applications special device technology is needed and usually supplied by GaAs ICs. However, silicon ICs are always attempting to compete with gallium arsenide for this market, which was reported to be $40 million in 1998.

A key parameter for the ATE devices is that of timing accuracy, where small variations in accuracy can move a borderline chip out of the guard band and into the trash can. On this basis the value of chips rejected in one year due to timing inaccuracies can exceed the cost of the AT equipment.Thus the economic value of the timing accuracy of the chips in the AT equipment becomes a key factor for the user of this equipment. GaAs ICs have subtle advantages for this application - they can be less expensive than Si; the GaAs buried p-well provides better intrinsic timing accuracy than Si; and GaAs has better temperature stability than Si (for example CMOS chips need heaters to keep their operating temperatures constant in order to achieve their best timing accuracy). For this application, Allan Armstrong from Vitesse (Camarillo, CA, USA) claimed that GaAs ICs are better overall than Si for the key reasons of speed and timing accuracy - additionally they are less expensive and have size and integration advantages over Si.

Competition

SiGe ICs continue to be a threat to GaAs devices in the lower frequency ranges. However, the cost performance advantage from 6" GaAs wafer lines may still remain with GaAs, because some of the Si IC technology advances shown in Table 1 could prove to be more of a challenge to SiGe ICs than to GaAs. This would be particularly true if the concern over the low (2 V) breakdown voltage of many SiGe devices is taken into account. However, some SiGe ICs could find their way into the market because higher device volumes are readily available to meet market needs from existing silicon fabs, whereas 6" GaAs fab capacity is quite limited and will remain so for some time.

At the high frequency end of the range (60 GHz and above), InP devices have been forecast to present a future challenge since larger wafers (up to 4" diameter) are now available and InP has traditionally been viewed as the preferred high frequency material. InP devices may

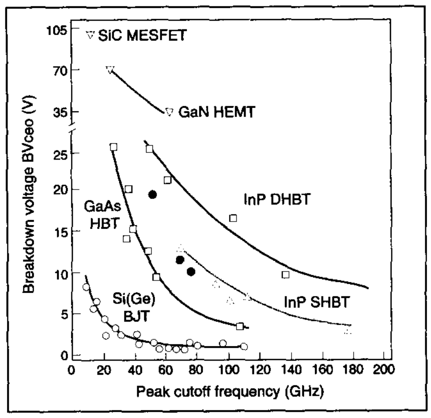

Figure 3. Breakdown voltage versus peak cutoff frequency for a selection of technologies (source: Nortel Networks).

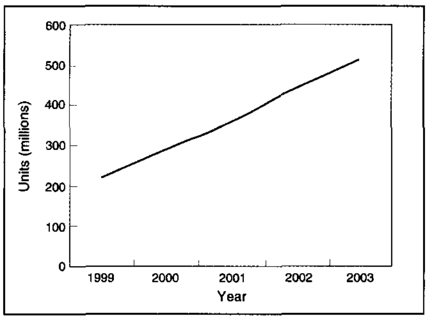

Figure 4. Forecast of worldwide production of cellular telephone and PCS handsets (source: Strategies Unlimited).

still represent significant competition in the future, as state-of-the-art devices become available, such as the InP HBTs and FETs with tunable linearity reported by TRW (Redondo Beach, CA, USA). Additional support for the commercial potential of InP may be inferred from the significant number of InP device papers that were presented at GaAs IC-21. Examples were multiplexers and frequency dividers operating in the 40 to 70 GHz range and a low power 50 GHz 4:1 multiplexer HBT. The recently reported heteroeptaxial InP on GaAs transistor processes could, however, be a reasonable compromise for the diehard GaAs devotees.

Fortunately, even in the above 60 GHz frequency range all is not lost for GaAs because it is mounting strong competition in this arena from several directions. For example, the latest performance reported for metamorphic HEMTs is now above 70 GHz. 77 GHz pHEMTS have been developed for automotive radar sensors; Vitesse's H-GAAS V process will operate at up to 86 GHz; a 97 GHz frequency divider has been reported by the Fraunhofer Institute; and, the 'prize winner', a 134 GHz InGaP/InGaAs HBT oscillator reported by Teratec Corp from Tokyo, with an output power of -10 dBm. Teratec's device is also claimed to be the highest-frequency fundamental mode oscillator ever reported using bipolar device technology.

Perhaps the real scenario is that GaAs is moving into the frequency domain once reserved for InP devices! From such data one can infer that the competition for existing and future GaAs system sockets continues unabated, from both Si and SiGe devices in the lower frequency ranges and InP at the top end of the range.

The improvements in frequency performance of Si device technologies through 2005, planned for the Silicon International Technology Roadmap Group, are shown in Table 1. These advances may not arrive quite in time with the tabled calendar, but their inevitability cannot be denied. However, their competitive effect may be felt more by SiGe devices because, as bandwidth demands increase, the operating frequencies will increase into ranges that still provide an advantage to GaAs, leaving SiGe as the looser. It is also possible that a 14 mask-level ion implant GaAs MESFET process on 6" wafers will be less expensive per die than a 24 to 28 mask-level BiCMOS process on 6 or 8" Si wafers. The above scenarios would provide a less competitive situation for GaAs ICs and further support the healthy growth forecasts for GaAs IC markets.

150 mm substrates

To support the projected growth rates and meet the competitive pressure for lower prices, 6" wafer processes have become an absolute necessity for GaAs IC makers and, fortunately, all the major wafer suppliers have 6" substrates available. In 1998, Vitesse was the only III-V device company making chips on 6" GaAs wafers and this year the company is in full production, well ahead of its competitors. More than 70 devices are now produced in the Vitesse 6" line with good fab yields. Most device yields are in the 70 to 90% range. Now Vitesse has been (or soon will be) joined by other GaAs IC manufacturers using 6" wafers, such as Anadigics, Infineon (formerly Siemens), Motorola, Tektronix, and RFMD. Thus the age of the 150 mm GaAs wafer has arrived as most of the GaAs players have announced their intent to have 150-mm wafer capabilities by early in 2001. Because of the availability of 6"-capable wafer process equipment off the shelf from Si equipment vendors, it is being proposed that even moderate-volume GaAs Fabs can now benefit from the installation of a 6" wafer Fab line. For Vitesse, wafer starts will increase to 2000 per week in 2000.

GaAs epitaxy

As the chip demand for cellular phones has increased, the market share for epitaxially grown devices has also increased to meet the demand for HEMT and HBT devices. This situation has created a virtual boom-market for both MOCVD and MBE equipment manufacturers. For these applications, the state-of-the-art capabilities are now five six-inch wafers for MOCVD units and four six-inch wafers for MBE systems, with multiple unit MOCVD systems already deployed at several companies.

The rapid growth in III-V epitaxy has also brought the long-

Table 1. The increasing performance of silicon

Year of first shipment	Min. feature size (nm)	fmax (GHz)	Transmit/receive frequency (GHz)	Device technology
1997	250	25	1.8-2.5	BJT/MOS
1999	180	35	2.5-3.5	BJT/MOS
2002	130	50	5-7	MOS
2005	100	65	9-11	MOS

Source: International Technology Roadmap for Semiconductors and SIA standing competition between ion implant (II) and epitaxial processes to the forefront. Although II MESFET processes now use six-inch wafers and support a growing $1.4 billion market, epi-based devices are growing at a higher rate, supported by HEMT and HBT device processes that are also available for six-inch wafers. However, there is one significant difference between the two processes: most of the II use is an in-house capability, whereas a large portion of the epilayer deposition capacity is available on a merchant basis.

The largest unit volumes for epi-devices are in the power amplifier and switch applications. When the sale of about 300 million handsets in 2000 (see Figure 4) is combined with a rapid buildup in the telephone support infrastructure, a continuing growth in epitaxy demand seems to be well assured. Particularly since, for these applications, epitaxy provides the best performance, the smallest die sizes and the benefits of a single power supply voltage.

The price of epi-wafers has often been stated as a deterrent to the growth of epi-based device market, but industry trends such as record chip demands, higher wafer throughputs and the availability of 6" wafers are leading to prices below the magic number of $455 per wafer. With over 50 epi-reactors in Taiwan, competition is assured. In the III-V industry, II and epitaxy processes are supposed to be competitors, but we should take another lesson from Si, where the best device performances are obtained from combining the two processes. Over 95% of Si devices use epitaxial- and II-device processes - *deja vue* - it will happen!

Ion-implantation

A formal panel discussion was created with the provocative title 'Is Ion-Implantation Dead or Dying?'. This reviewed the relative pros and cons of the two technologies. As may be anticipated in the real world, the II process is not dead; it provides useful enhancement and depletion mode devices and has advantages where passive components affect the IC die sizes. Its proponents currently claim it to be the best process for GaAs device yield and process cost. Therefore, as noted earlier, there is plenty of growth potential left in the II process to supply the healthy digital IC market. And in the speed of operation category, II ICs are no laggards, with Vitesse's H-GAAS IV process producing ICs with up to 46 GHz ratings and next year's H-GAAS V process devices are expected to top off at 83 GHz. The discussion therefore concluded that, for now, II processes will continue to support a strong and growing device market without too much interference from epitaxy.

Novel GaAs applications

Long wavelength infrared (IR) imaging, in the 8 to 12 μm atmospheric window, has several military and commercial uses. These include: security and surveillance, navigation and targeting, industrial process control, medical imaging, the astronomical study of cold objects, and the study of atmospheric chemistry (e.g. the monitoring and measurement of gas compositions and pollutant levels in the air). Quantum well IR photodetectors (QWIPs) have become a possible candidate for these applications, which include the 8-12 μm window.

Related to these applications, a novel GaAs development was reported by Mani Sundaram, from Sanders, Lockheed Martin (Nashua, NH, USA), who described the fabrication of two-colour QWIP focal plane arrays that produced spatially registered simultaneous imagery and both long wave (LW) and medium wave (MW) formats. Typical MBE InGaAs/GaAs/AlGaAs growth processes could be used for manufacture of the LW/LW, MW/LW, and MW/MW array formats. For these two-colour array detectors, three mounting bumps per pixel were used to permit the assembly of two vertically stacked and separately biased QWIPs and also retain the ability to simultaneously integrate the two photocurrents. MBE growth consistently produced single colour focal plane array QWIPs that exhibited a 15% quantum efficiency when operating in the 65 to 77 K temperature range. For these and other reasons QWIPs have also become the device of choice to make sensitive and cost-effective long wave IR staring arrays.

For the first time, two-colour pixel-registered imaging was demonstrated in several colour combinations and the first two-level long wavelengths were produced. This technology is believed to be robust enough to extend to larger than 640x480 pixel formats and to at least four simultaneous colours. An interesting example of the two different wavelength sensitivities is that of rain on a car windshield: the medium wavelength detector sees the rain on the car window, but the long wavelength IR does not detect the rain and sees right through it.

In conclusion, it can be reported that GaAs IC-21 was a successful meeting, which presented a variety of newsworthy papers covering high frequency device technology. It demonstrated strong support for the future growth of a multi-segmented GaAs IC market. Everyone appeared to be in a positive mood, the vendors claimed to be happy and at this time, the outlook for the GaAs IC future is as strong as it has ever been.

Contact: Dr Alan Mills
PO Box 4098
Mountain View
CA 94040, USA.
Tel: +1-650-968-2383.
Fax: +1-650-968-8416.
E-mail: amills@inreach.com.